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SCROLL COMPRESSOR DESIGN CRITERIA FOR RESIDENTIAL
AIR CONDITIONING AND HEAT PUMP APPLICATIONS
PART II: DESIGN CRITERIA

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SCROLL DESIGN CRITERIA

Because the scroll is a unique technology, many design criteria utilized previously by reciprocating and rotary compressor designers must be modified to achieve an optimal scroll product in terms of both high performance and durability. Operational characteristics related to the optimal performance and durability of the product in an air conditioning and heat pump system are discussed here.

Efficiency

Just as the heart of a refrigeration system is the compressor, the scroll components are the heart of the scroll compressor. To achieve the optimal scroll design for a given size compressor, various geometric parameters such as vane height to width ratio and involute generating radius must first be selected as was done by Bush, et al. [6] to minimize energy losses. Next, a scroll machining process must be developed for fast, efficient machining to tolerances of less than 0.01mm on both vane profile and tip-to-base height. Finally, a gaging concept and computer software are necessary to determine operational clearances between the scroll vanes and tip-to-base contacts at all positions of crank rotation. With a fully compliant scroll design, radial (flank) contact for each crank position is assured at one point and axial (tip-to-base) contact will occur at three points. All other non-contact points represent potential zones for gas leakage and rely heavily on accurate machining to control flow losses. Of the two leakage possibilities, leakage through the scroll flanks is at most one-half the sensitivity of leakage at the tip-to-base contact due to the longer leak path associated with the flanks and the longer leak perimeter associated with the tips.

Operating Range

Consistent performance over a broad range of compressor operating conditions is particularly important for heat pump compressors which must generally operate effectively for pressure ratios of 2 to 7. By concept, the scroll compressor is a fixed volume ratio machine with optimal efficiency obtained only at the design compression ratio. For compression ratios above or below the design ratio, efficiency is reduced with the more significant loss occurring at compression ratios below the design ratio. Therefore, by selecting a design compression ratio near the low end requirement, an optimal compromise is obtained for scroll compressor efficiency over a broad range of compression ratios. Figure 15 compares scroll efficiency to a high efficiency reciprocating compressor over compression ratios required for air conditioning and heat pump operation.

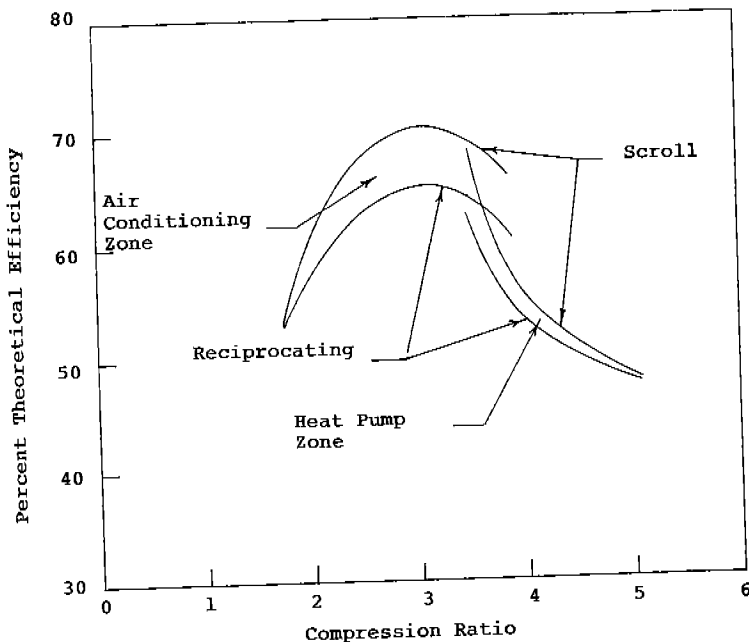


Figure 15 Compressor Efficiency vs. Compression Ratio

Flank and Tip-to-Base Loading

Optimal scroll efficiency is highly dependent on the contact forces between the mating scroll surfaces with the obvious design compromise being to provide enough force to ensure good sealing while generating minimal frictional force components. For fully compliant scrolls, both radial (flank) loads and axial (tip-to-base) loads must be optimized over the desired operating range of the compressor. Flank contact is ensured if the centrifugal force of the orbiting scroll mass is sufficient to significantly overcome a gas pressure unloading force which is directly proportional to the pressure differential across the compressor. Since the highest compressor pressure differentials occur at high ambient air conditioning, positive flank contact at this operating condition will ensure flank sealing over the entire operating range.

Tip-to-base loading associated with axial compliance can be maintained at a relatively constant low value when gas loading is applied to the fixed scroll as shown in Figure 8. In addition, during the compressor startup phase when high and low side pressures are balanced, a positive tip load is generated due to the pressurization of the intermediate cavity by the scroll compression process. This ensures that axial scroll sealing (high volumetric flow) is maintained during both transient start up and steady state operating modes. One practical aspect of this feature, which is essential for proper heat pump system operation, is the actuation of the system reversing valve which is activated by a pressure differential resulting from compressor mass flow.

Noise

Due to the nearly continuous flow processes of the scroll compressor, gas pulsations make a negligible contribution to overall compressor noise. The primary source of scroll noise is mechanical contact between the mating scrolls.

Some design approaches avoid this problem by eliminating radial flank contact at the sacrifice of sealing efficiency. However, proper machining of the contacting scroll flanks can achieve noise levels comparable to non-compliant scroll designs.

Starting

Compressor startup during all system operating modes must be assured by the system designer. With reciprocating and rotary compressors, system pressures must be balanced to allow the compressor to start without the aid of special starting components. If starting components are not employed, a time delay circuit is usually required to ensure system pressures are balanced prior to compressor restarting. With the scroll compressor, a check valve is required to prevent compressor backward operation during system off periods. This check valve also allows the compressor to restart almost immediately after a rapid internal balance of high and low side pressures. Fewer system components and thus reduced costs result with the use of a scroll compressor.

In addition to inherent scroll starting capabilities, some design features can be employed to enhance scroll compressor starting. First, with radial or axial compliance, scroll leakage is high during startup and minimal motor torque is required to overcome compression or frictional work. This augments an unbalanced pressure starting ability which is superior to other technologies where startup unloading is not possible. Another feature which enhances starting is the motor straddle bearing system illustrated in Figure 13. This system minimizes bearing friction due to pullover forces resulting from a non-centered motor rotor. Scroll compressors using this bearing approach start equally well with centered or non-centered rotors.

Durability Criteria

A high tolerance to liquid and contaminant ingestion was previously identified as an important durability feature of a fully compliant scroll compressor. For high contaminant tolerance, radial compliance is most critical. For high liquid tolerance, axial compliance is necessary to prevent the generation of high pressures during liquid passage. In most other durability areas such as bearings, lubrication, and component wear, fully compliant scroll compressors compare favorably to reciprocating types. Due to the ability of the compliant scroll design to adjust for minor wear, continued performance and durability can be expected.

Temperature Protection

During system failure modes such as loss of charge or evaporator fan failure, the inherent high volumetric efficiency of the scroll compression process results in higher than normal compression ratios. High discharge gas temperature can result which, in turn, causes oil breakdown and scroll component damage. To guarantee positive compressor protection during system failure modes of operation, a discharge thermostat is required to sense dangerous discharge temperatures and remove power to the compressor. To be effective, this thermostat should be in close proximity to the scroll discharge port. With this approach, compressor discharge temperatures are limited to 300°F and compressor damage is minimized. However, with total loss of system charge, air can enter the system and cause moisture related contamination. Under this mode of operation, scroll compressors with thermostat protection have demonstrated longer survival times than comparable reciprocating products.

SCROLL DESIGN EXAMPLE

Figure 16 is a cross-sectional drawing of a scroll compressor product which meets the design criteria identified previously. This product is the culmination of over ten of years research and development with the last three years being a focused development effort to define the engineering and manufacturing techniques necessary to make the scroll a practical product for high volume production. Residential air conditioning and heat pump systems from 2 to 3-1/2 tons were selected as the first application for this product. Some specific product features are given below:

- Low side (low pressure) shell for optimum thermal and sealing efficiencies.
- Axial compliance with fixed scroll gas loading for optimal tip loading.
- Radial compliance for flank load control, sealing, and contaminant tolerance.
- Optimized scroll vane geometry for maximum overall efficiency.
- Low compression ratio optimization for high air conditioning efficiency.
- Main bearings across the motor for minimal bearing loss and excellent starting.
- Temperature protection for loss of charge and other system failure modes.

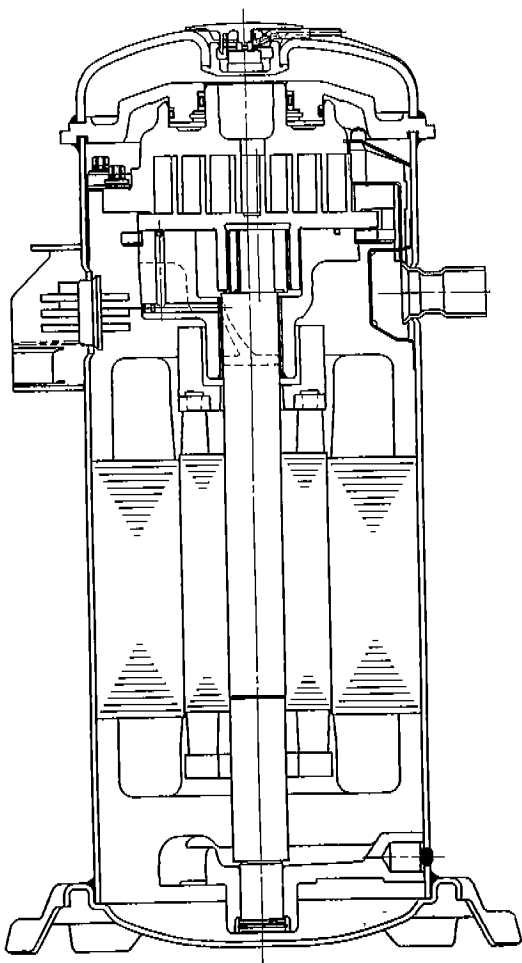


Figure 16

Typical performance data is:

- Capacity Range--22,000 BTU/hr to 59,700 BTU/hr
- Energy Efficiency Ratio--11.0 @ ARI air conditioning rating point.
- Sound Power--66 dBA
- Vibration--0.05mm peak-to-peak maximum
- Oil Circulation Ratio--less than 0.5percent by mass

In summary, the product performance levels given here significantly surpass existing products of all technologies. In the case of currently available reciprocating compressors, the scroll efficiency gain is 7 to 10 percent and the noise level reduction is 4 to 6 dBA. Future scroll development will likely yield further improvements in both efficiency and noise with projected energy

efficiency ratios as high as 12.0 and noise levels as low as 63 dBA. At this stage of scroll compressor development, there is good reason to be optimistic about the future growth of this technology. As durability and cost are demonstrated to be as superior as efficiency and low noise, scroll products will become the future of the air conditioning and refrigeration compressor business.

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